P-10.1 Summarize the first and second laws of thermodynamics.

Revised Taxonomy Level 2.4 <u>Summarize</u> conceptual knowledge

In physical science students

- "Explain the process of phase change in terms of temperature, heat transfer, and particle arrangement."(PS-3.7)
- "Explain how the law of conservation of energy (including mechanical energy, electrical energy, chemical energy, light energy, sound energy, and thermal energy)." (PS-6.1)

It is essential for students to

- Understand that the internal energy of a substance is the total of all of the energies inside of a substance including
  - Kinetic energy of jostling molecules
  - Rotational kinetic energy of molecules
  - Kinetic energy due to internal movements of atoms within the molecules
  - Potential energy due to the forces between molecules
- Understand that the first law of thermodynamics
  - Can be generally stated as: "Whenever heat is added to a system, it transforms into an equal amount of energy that may include other forms."
    - You cannot get any more energy out of a system than you put in.
    - This is a restatement of the law of energy conservation applied to heat.
  - The heat that is added to a system can do one or both of two things:
    - If it remains in the system it will increase the internal energy of the system (by increasing any combination of the forms listed above)
    - If it leaves the system it will do external work on another system
- Understand that the second law of thermodynamics
  - Can be generally stated as: "When energy transforms, some of it degenerates into waste. The wasted energy is unavailable and is lost."
  - You cannot get as much energy out as you put in.

Assessment

The revised taxonomy verb summarize means "to abstract a general theme or major point" For this indicator, the major focus of assessment should be to insure that students have a deep conceptual understanding of the terms system, internal energy, heat, and work. Conceptual knowledge requires that students understand the interrelationships among the basic elements within a larger structure that enable them to function together. In this case, that students understand the how the Law of conservation of energy is applied to thermal systems, in terms of work and internal energy.

P-10.2 Explain the relationship among internal energy, heat, and work.

Revised Taxonomy Levels 2.7 B Explain conceptual knowledge

Students did not address this concept in physical science

It is essential for students to

- Be able to use the equation $Q = \Delta E + W$, where
  - Q = heat transferred to a system (in joules)
  - ΔE = the change in the internal energy of a system (in joules)
  - W = work done on surrounding objects (in joules)
- Understand that
  - Q is positive when energy is transferred to the system (and negative when energy is transferred out of the system)
  - W is positive when the system does work on surrounding objects (and negative when the surroundings do work on the system)
- Understand that a process in which no heat is added to or removed from a substance is called an adiabatic process
  - $Q = 0 = \Delta E + W$
  - $\Delta E = -W$
  - The work done on the system = the change in its internal energy

Assessment

The verb, explain means that the major focus of assessment should be for students to "construct a cause and effect model". In this case, assessments will ensure that students can model how heat affects the internal energy of a system and the work that that system can do on the surroundings. Because the indicator is written as conceptual knowledge, assessments should require that students understand the "interrelationships among the basic elements within a larger structure that enable them to function together." In this case, assessments must show that students can construct a cause and effect statement relating how changes in each of these three variables, heat, internal energy, and work affect the others.

P-10.3 Exemplify the concept of entropy.

Revised Taxonomy Level 2.2-B Exemplify conceptual knowledge

Students did not address this concept in physical science

It is essential for students to

- Understand that entropy is a measurement of the amount of disorder in a system
- Understand that entropy can be expressed as a mathematical equation, stating that the increase in entropy, ΔS, in and ideal thermodynamic system is equal to the amount of heat added to a system, ΔQ, divided by the temperature, T, of the system: $\Delta S = \Delta Q/T$.
- Entropy is a manifestation of the second law
  - Whenever energy freely transforms from one form to another, the direction of transfer is toward a state of greater disorder.
  - The entropy of the universe is always increasing.
- Explain familiar systems in terms of entropy
  - Gas molecules escaping from a bottle.
  - Heat always flows from a hot object to a cold object.
  - Efficiency of machines is always less than 100%.

Assessment

The verb exemplify means to find a specific example or illustration of a concept or principle, therefore the major focus of assessment will be for students to give examples that show that they understand how familiar energy transformations are based on the principle of entropy increase. Conceptual knowledge requires that students understand the interrelationships among the basic elements within a larger structure that enable them to function together; in this case, that students understand the laws of thermodynamics as they apply to familiar systems

P-10.4 Explain thermal expansion in solids, liquids, and gases in terms of kinetic theory and the unique behavior of water.

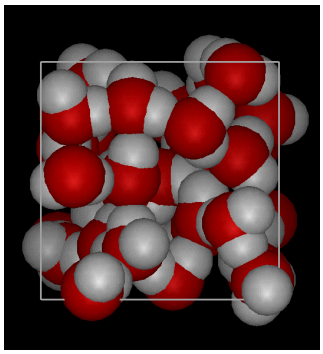
Revised Taxonomy Levels 2.7 B <u>Explain</u> conceptual knowledge

In physical science, students

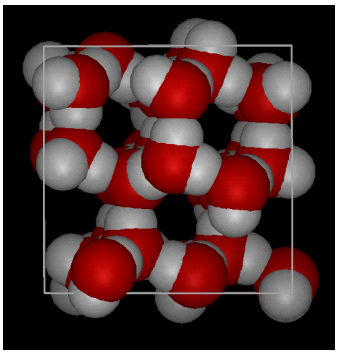
- Compare the properties of the four states of matter—solid, liquid, gas, and plasma—in terms of the arrangement and movement of particles. (PS-3.6)
- Explain the processes of phase change in terms of temperature, heat transfer, and particle arrangement. (PS-3.7)

It is essential for students to

- Understand the two basic concepts of the kinetic theory
  - The molecules of a substance are in constant motion
    - The amount of motion depends upon the average kinetic energy of the molecules; this energy depends upon the temperature.
  - Collisions between molecules are perfectly elastic (except when chemical changes or molecular excitations occur).
- Explain thermal expansion in solids both conceptually and mathematically
  - The change in length of a solid equals the product of its original length, its change in temperature, and its coefficient of linear expansion.
    - For the same increase in temperature, different materials of the same length expand by different amounts (depending upon the nature of the molecules which comprise the materials)
    - The coefficient of linear expansion is a value which indicates the change in length per unit length of a solid when its temperature is changed one degree
  - $\Delta\ell = \alpha\, \ell\, \Delta T$ where
    - $\Delta\ell$ = the change in length
    - α = the coefficient of linear expansion
    - ℓ = the original length
    - ΔT = the change in temperature
- Explain how the combined effects of molecular motion and crystalline structure result in water being the most dense at a temperature of 4° C.



Structure of liquid water



Structure of ice

- Explain the expansion of gasses in terms of Charles' Law
  - $V' = VT_k'/T_k$ Where
    - V' = The new volume of a gas
    - V = The original volume of a gas
    - T_k'= The new temperature (Kelvin)
    - T_k = The original volume (Kelvin)

Assessment

The verb, explain means that the major focus of assessment should be for students to "construct a cause and effect model". In this case, assessments will ensure that students can model the thermal expansion of substances, in terms of the kinetic theory. Because the indicator is written as conceptual knowledge, assessments should require that students understand the "interrelationships among the basic elements within a larger structure that enable them to function together." In this case, assessments must show that students can construct a cause and effect statement relating how temperature affects the kinetic energy of the particles of substances in various phases and how the change in kinetic energy affects the volume of the substance.

P-10.5 Differentiate heat and temperature in terms of molecular motion.

Revised Taxonomy Level 4.1B Differentiate conceptual knowledge

Physical Science students did not address this topic.

It is essential for students to

- Understand that heat is thermal energy that is absorbed, given up, or transferred from on body to another, while temperature of a body is a measure of its ability to give up heat or absorb heat from another body.
  - Heat will flow from a body with a higher temperature to a body with a lower temperature, even if the cooler body contains more thermal energy.
- Understand that temperature is an indication of the average kinetic energy of the particles of a substance.
  - Because it is an indication of the average kinetic energy, a liter of boiling water and two liters of boiling water will have the same temperature
- Understand that internal energy is an indication of the total internal energy (potential and kinetic) of the particles of a substance
  - Because it is an indication of the total internal energy, there is twice as much thermal energy in two liters of boiling water as in one liter.
- Heat is measured in units of joules, temperature in degrees Celsius, degrees Fahrenheit, or Kelvin

Assessment

As the verb for this indicator is differentiate, the major focus of assessment should be for students to distinguish between the relevant and irrelevant parts or important from unimportant parts of presented materials. Because the verb is differentiate, rather than compare, students thoroughly understand the terms temperature and heat in terms of the kinetic theory. Because the indicator is written as conceptual knowledge, assessments should require that students understand the "interrelationships among the basic elements within a larger structure that enable them to function together." In this case, assessments must show that students understand how heat and temperature effect and are affected by the internal energy of a substance.

P-10.6 Summarize the concepts involved in phase change.

Revised Taxonomy Level 2.4 Summarize conceptual knowledge

In Physical Science, students

- "Explain the processes of phase change in terms of temperature, heat transfer, and particle arrangement" (PS-3.7)

It is essential for students to

- Understand that the internal energy of a substance (the energy of the particles) is of two types, kinetic and potential.
  - The potential energy of the particles of a substance is due to the attractive force between the particles.
  - The kinetic energy of particles depends upon their speed
    - Temperature is a term used to describe the average speed the particles are moving, and therefore the average kinetic energy of the particles. (some move faster than others.)
    - The faster a particle is moving the more kinetic energy it has
- Explain phase change in terms of The Kinetic Theory
  - Phase change due to *increasing* the energy of the particles
    - When energy (such as heat) is added to a substance, the energy of the particles of the substance is increased, either by increasing the potential energy of the particles or by increasing the kinetic energy of the particles.
    - Both the potential energy and the kinetic energy of the particles of a substance can not increase at the same time, so both the phase and the temperature of a substance can not change at the same time.
    - Usually when energy is added to a substance, only the speed of the particles increases, they do not get further apart; so only the kinetic energy of the substance increases, not the potential energy.
      - Evidence of this would be that the temperature of the substance increases but the phase does not change
    - In order for the phase of a substance to change, energy (such as heat) must be added to a solid which is at a temperature equal to its melting point or to a liquid which is at a temperature equal to its boiling point
    - As soon as all of the particles have overcome the forces, and the phase of the substance is completely changed, then, added energy will once again be converted to kinetic energy, the phase will not change, the speed of the particles will increase, and a temperature increase will be observed.
  - Phase change due to decreasing the energy of the particles
    - Usually when energy is removed from a substance, only the speed of the particles decreases, they do not move closer together; so only the kinetic energy of the substance decreases, not the potential energy.
      - Evidence of this would be that the temperature of the substance decreases but the phase does not change

- In order for the phase of a substance to change, energy (such as heat) must be removed from a liquid which is at a temperature equal to its freezing point or a gas which is at a temperature equal to its condensation point.
- As soon as all of the particles have changed phase, removing energy will once again result in a decrease of kinetic energy, the speed of the particles will decrease, and a temperature decrease will be observed.

Assessment

The revised taxonomy verb, summarize means "to abstract a general theme or major point" For this indicator, the major focus of assessment should be to insure that students have a deep conceptual understanding of the processes involved in phase change and can describe these processes in terms of the kinetic theory. Conceptual knowledge requires that students understand the interrelationships among the basic elements within a larger structure that enable them to function together. In this case, that students understand the effect that heat being transferred into our out of a substance has on the phase and the temperature of a substance.

P-10.7 Apply the concepts of heat capacity, specific heat, and heat exchange to solve calorimetry problems.

Revised Taxonomy Level 3.2 C_A Apply (use) procedural knowledge

Students did not address this concept in physical science

It is essential for all students to

- Understand that the specific heat capacity (c) of a substance is the amount of heat required to change the temperature of one gram of a substance one degree Celsius.
  - $Q = mc\Delta T$ where
    - Q = heat (in joules)
    - m = mass (in grams)
    - c = specific heat capacity (in joules/gram Celsius degree)
    - ΔT = the change in temperature (Celsius degrees)
- Understand that the heat of fusion (L_f) of a substance is the amount of heat needed to melt a unit mass of a substance at its melting point
  - $Q = m L_f$ where
    - Q = heat (in joules)
    - m = mass (in grams)
    - L_f = the heat of fusion
- Understand that the heat of vaporization (L_v) of a substance is the amount of heat needed to vaporize a unit mass of a substance at its boiling point
  - $Q = m L_v$ where
    - Q = heat (in joules)
    - m = mass (in grams)
    - L_v = the heat of vaporization
- Solve problems involving heat lost or gained resulting in both temperature changes and phase changes

Assessment

The revised taxonomy verb for this indicator is implement (apply), the major focus of assessment will be for students to show that they can "apply a procedure to an unfamiliar task". The knowledge dimension of the indicator, procedural knowledge means "knowledge of subject-specific techniques and methods" In this case the procedure for solving problems involving heat lost or gained resulting in both temperature changes and phase changes